

LARVAL DEVELOPMENT OF THE BARNACLE *TETRACLITELLA* *KARANDEI* REARED IN THE LABORATORY

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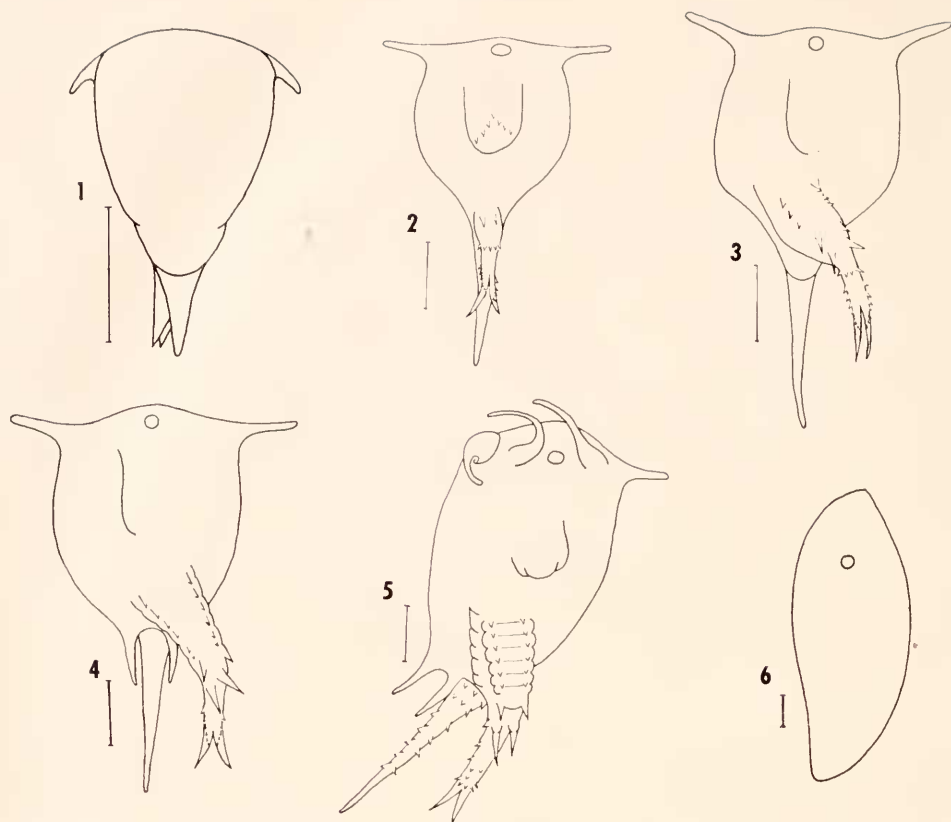
Tetracrita purpurascens Wood and *Tetracritella karandei* Ross are two common tetracritellan species encountered at Madh Island off the Bombay coast of India. *T. karandei* occurs on the undersurface of rocks, low in the intertidal zone, where it normally remains moist during periods of low tides. Ross (1971, page 215) observes that "ecological conditions under which this species lives and the few animals with which it is associated do not differ appreciably from those of other species of *Tetracritella*."

The diagnostic characters of *T. karandei* as stated by Ross (1971, page 217) are "radii transversely ridged, the apical 3-4 ridges extending like fingers out and over adjoining plate, scutum transversely elongated, externally ornamented with prominent nodes where longitudinal ridges cross growth lines, intermediate articles of posterior cirri armed with three pairs of setae." Ross has cautioned that this new species is similar in many ways to the widely occurring *T. purpurascens* and records of the latter species should be re-evaluated in the light of his discovery.

The larval development of some temperate and tropical species of balanids has been studied by various workers. There has been, however, no published account of the larvae of any tetracritid barnacles. The development of *T. karandei* was therefore examined under laboratory conditions with a view to describing each of its six nauplii and the cyprid larva. The naupliar characters such as setation of antennule, carapace sculpture, and abdominal and caudal processes have been examined and are compared with those of megabalanid, balanid, chthamalid and pedunculate species encountered in Bombay waters. Due to the paucity of the gravid specimens, it has not become possible to describe larval antennae and mandibles of *T. karandei* in the present paper. The characters described, however, are adequate to separate these larva from those of other species. Earlier Karande (1973a) reported on the larvae of *Balanus amphitrite amphitrite* and on the larvae of *Balanus variegatus* (Karande; in press, 1973b). Some of the other species examined in this laboratory are *Balanus amaryllis eumaryllis*, *Chthamalus withersi*, *Chthamalus malayensis*, *Ibla cumingi*, and one unidentified species of balanid. The systematic position of this unknown balanid barnacle is still being investigated.

MATERIAL AND METHODS

Small pieces of stone bearing specimens of *T. karandei* were maintained in small glass jars of natural sea water. The adults were fed daily on a diet of *Dunaliella primolecta* and the diatoms *Plurosigma* sp. and *Phaeodactylum* sp. The sea water was changed every day, and the specimens were kept dry during night hours. The embryos or the first nauplii released by these adults were reared to obtain their



FIGURES. 1-6. Larval stages of *Tetrachitella karandei*; all scale bars equal 100 μ . Figures 1, 2, 3 and 4 are first, second, third and fourth naupliar stages respectively. Figure 5 is the sixth nauplius and Figure 6 the cyprid larva.

subsequent growth stages. A general outline of the rearing technique has been earlier reported by Karande and Thomas (1971).

RESULTS

Description of the larvae

The first nauplius, usually measuring 240 μ , has a pear-shaped body (Fig. 1). Anterior horns, 50 μ long, are very clearly seen. Both the abdominal and the caudal processes are very well differentiated and each one of them measures 50 μ in length. A median eye is present. Frontal filaments have not appeared. The antennule shows a setal pattern of 0-0-0-1-2-1-1-0. The actively moving larvae transform into second nauplii in about one hour's time. Table I gives the dimensions of various cirriped larvae examined in this laboratory. Table II gives the dimensions of various appendages of *T. karandei* larvae.

The second nauplius is twice the size of the first because of a considerable elongation of the caudal process (Fig. 2). It is 480 μ long, and is almost as big as the

TABLE I

Dimensions in microns of nauplius and cyprid larvae of eight cirriped species from Bombay

Stages	<i>T. karandei</i>	<i>B. variegatus</i>	<i>B.a. amphitrite</i>	<i>Ch. withersi</i>	<i>Ch. malayensis</i>	<i>B. amaryllis euamaryllis</i>	<i>Balanus</i> sp.	<i>I. cumingi</i>
I	240	240	225	205	216	240	190	300
II	480	390	300	300	300	480	280	372
III	540	400	310	330	360	500	335	385
IV	600	425	425	360	415	600	395	420
V	700	540	460	420	420	670	480	460
VI	780	580	540	480	450	*	530	500
Cyprid, carapace	600	615	510	480	420-80	*	*	565

* Notrecorded.

second nauplius of *B.a. euamaryllis*. The latter may at times achieve a length of 500 μ and is the biggest second nauplius encountered in Bombay waters. The frontal filaments emerge but are only 30 or 40 μ long. The frontal horns are 85-90 μ long. The median lobe of the labrum is hairy and two other lobes bear very minute teeth. These teeth are missing in the subsequent stages. A highly spinulated caudal process is 200 μ long (Fig. 7, cds). The spinules are generally subequal. At two localized places, however, some spinules are slightly bigger than the rest. The base of the caudal spine is also spinulated. The abdominal process, which is shorter than the caudal process, has a well defined 80 μ long stem and two 70 μ long massive rami. At early stage, the stem has two well defined ringlets of spinules, a proximal one and a distal one. Of these the former one gets disorganized at the late second nauplius stage. The stem and the furca are thus separated by a distal ringlet of spinules. Each ramus bears a row of spines along its outer margin which runs half-way down the ramus and encircles it to form a ringlet of spinules. A distal half of the ramus is smooth. A pair of distal abdominal spines is present on a bulged abdominal process. These spines appear on a common base

TABLE II

Dimensions in microns of some larval features in Tetraclitella karandei

Larval stage	N I	N II	N III	N IV	N V	N VI	Cyprid
Total length	240	480	540	600	700	780	*
Carapace length	**	**	**	470	540	625	600
Post. carapace spine	**	**	**	80	85	110	**
Frontal filament	**	50	85	*	*	*	180
Frontal horns	50	85	85	*	*	70	**
Caudal process	50	200	270	300	300	260	**
Abdominal process	50	155	180	240	240	205	**
Distal abdominal spine	**	10	25	30	45	50	**
Proximal abdominal spine	**	**	10	10	25	35	**
Rami	25	70	85	*	*	95	**

* Not recorded.

** Absent.

and after undergoing some changes in shape and size separate into two individual, well defined spines. The setal formula for the antennule is 0-0-0-4-2-1-1-0.

The third nauplius measuring 540 μ in total length resembles the second nauplius in general morphology (Fig. 3). The frontal filaments are 85 μ long. The abdominal process measuring 180 μ , now bears proximal pair of the abdominal spines. Three pairs of segmental spines are present. The stem and the furca of the abdominal process are 95 μ and 85 μ respectively. A characteristic feature of this stage is an emergence of a preaxial seta on the antennule whose setal formula now reads 0-0-1-4-2-1-1-0.

The fourth nauplius is 600 μ long (Fig. 4). A true carapace developed at this stage is 470 μ long and 300 μ wide. The paired posterior carapace spines are 80 μ long; 120 μ long anterior horns direct ventro-laterally. The abdominal bulb, besides several minute spinules, bears a few characteristic spines each one of which is beset with minute hair(s) on its base (Fig. 8 abs). The abdomen is demarcated into segments by a series of sub-equal spinules. The abdominal appendages, now in the form of ill-defined papillae, are seen under the exoskeleton. Six pairs of segmental spines are clearly seen. The proximal and the distal abdominal spines are 10 and 30 μ long respectively. The antennule has two preaxial setae and its setation formula is 0-1-1-4-2-1-1-0.

The fifth nauplius, measuring 700 μ in total length, has a massive body. An elongated abdomen is very clearly segmented and the cirriform appendages, now in the form of well-defined papillae, are seen under the exoskeleton. The 240 μ abdominal process continues to be shorter than the caudal process. The spinulation pattern of the abdominal bulb remains unchanged from that of the earlier stage. The 25 μ long proximal abdominal spines move more laterally than 45 μ long distal abdominal spines. The former ones are short, stumpy with small pointed ends and the latter ones are long, slender with hyaline appearance. These two pairs of spines stay fairly apart from each other unlike those of *B.a. amphitrite* and *B.a. euamaryllis*. In the latter two species, these pairs approach closer at this and the following metanauplius stage. The spinulation on the stem portion of the abdominal process is considerably reduced and a ringlike pattern of the spinules on each ramus is largely disturbed. The terminal segment of the antennule becomes strikingly longer and the sub-terminal one becomes broad and bulbous. The setal pattern for the antennule is now 1-1-1-4-2-1-1-1.

The sixth larva is the largest metanauplius so far studied from the Indian Waters (Fig. 5). Measuring 780 μ in total length, it is about 200, 240, 280 and 300 μ longer than the metanauplii of *B. variegatus*, *B.a. amphitrite*, *I. cumingi* and *Ch. withersi* respectively. Its carapace, excluding the posterior carapace spines is 515 μ long and 410 μ wide. The carapace spines are 110 μ long. Each of the frontal horns is 70-75 μ long. The labrum is 160 μ long. A massive abdomen occupies most of the space under the carapace. Six pairs of segmental spines are present. Fully grown, the proximal and the distal abdominal spines are 30 and 50 μ long respectively. The spinules on the stem of the abdominal process become scarce and those on the rami lose their ringlike pattern so clearly observed at earlier naupliar stages. Many of these spinules crowd at the angle formed by the two rami. Each ramus is 95 μ long. The caudal process retains a few spines both on the body and on its base. The antennule now shows a setal pattern of 1-1-1-4-2-1-2-1. The metanauplius has three naupliar eyes.

TABLE III

Dimensions in microns of some cyprid features in six cirriped species from Bombay

Barnacle species	Carapace length	Carapace (l/w) ratio	Abdominal cirri	Caudal cirri	Antennular vacuum pad, diameter	Oil globules diameter
<i>T. karandei</i>	600	2.50	135	110	40	25
<i>B. variegatus</i>	615	2.23	120	100	*	10-35
<i>B.a. amphitrite</i>	510	2.15	*	*	50	15
<i>Ch. withersi</i>	480	2.23	95	85	35	*
<i>Ch. malayensis</i>	480	2.18	90	50	*	*
<i>I. cumingi</i>	565	2.22	120	*	30	25

* Not recorded.

The cyprid measuring 600 μ in carapace length is an extremely active larva (Fig. 6). A pair of massive antennules and the caudal appendages are constantly held out of the carapace. A delicate and transparent 240 μ wide carapace is boat-shaped and reveals encased soft body parts very clearly. Table III gives ratios of the length and the width (l/w) of the carapace of cyprids of various species examined in this laboratory. This ratio is the highest in respect of *T. karandei* cyprid. The presence of 180 μ long frontal filaments is a distinctive character of this cyprid. In no other cyprid these long filaments are observed. Each ramus of the abdominal appendages has four segments. The cirri on the abdominal appendages and the caudal appendage measure 130 and 110 μ respectively. A diameter of the antennular vacuum cup is 35 μ . The diameter of the oil globules present in the anterior half of the carapace is about 20-30 μ . Table III also gives the dimensions of the appendages of various cyprids examined in this laboratory.

Characters of diagnostic interest

The setation of antennule in *T. karandei* conforms to that of many tropical and temperate species examined by various workers. There are no preaxial setae at stages I and II and the first preaxial seta appears at stage III. There is addition of one each at stages IV and V. The fifth nauplius shows five post-axial setae and the sixth one has six of them. All the eight widely separated barnacle species examined in this laboratory show identical setal pattern. This character alone, therefore, is of no assistance in separating the larvae of one species from those of the other. However, since the number of setae is specific for each stage, it is possible to distinguish one stage from the other.

In *T. karandei* a true carapace with posterior carapace spines develops at stage IV. *T. karandei* larvae can be easily separated from the others by virtue of their long carapace spines (80 μ at stage IV and 110 μ at stage VI). No other species examined from Bombay waters has a carapace spine longer than 70 μ (Table IV). The carapace spine and spinulation is of considerable help in separating cirriped larvae encountered in Bombay waters. In the two chthamaliid species studied, these posterior carapace spines are totally absent. In all other barnacles, the spines of varying lengths are present. A separation of the larvae is also possible on the basis of the presence or the absence of spinulation on the carapace border. In all the six nauplii of *B.a. eumaryllis* and *B. variegatus* the spinulation is present

TABLE IV

Comparison of naupliar carapace sculpture in eight cirriped species from Bombay

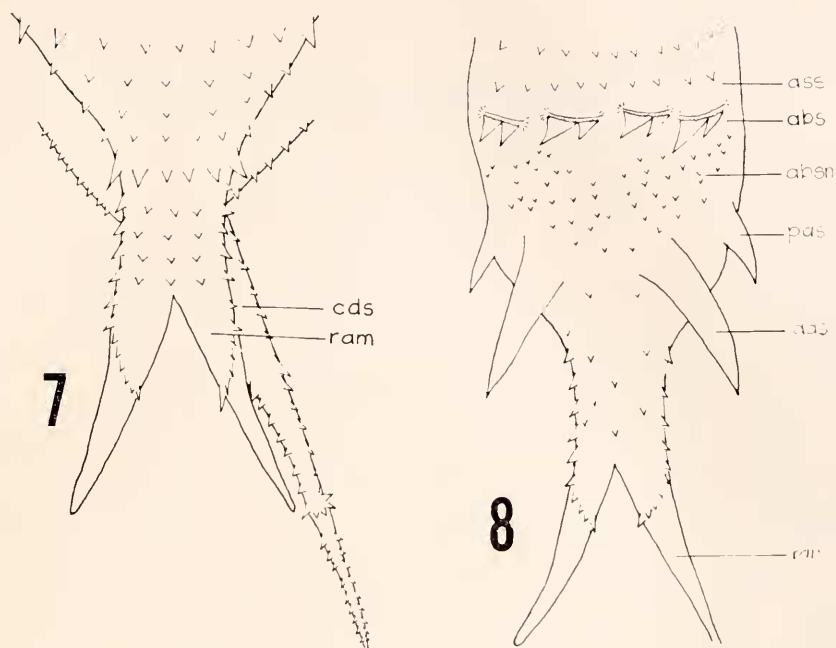
Barnacle species	Posterior carapace spines and lengths in μ			Carapace spinules	Carapace spinules
	IV nauplius	V nauplius	VI nauplius	False carapace, II and III nauplius	True carapace, IV, V and IV nauplius
<i>T. karandei</i>	80	85	110	Absent	Absent
<i>B.a. amphitrite</i>	35	35	15	One pointed spinule on either side	Absent
<i>B. variegatus</i>	35	50	45	Subequal spinules on entire border and on basal part of horn	Spinules persist
<i>B.a. cuamaryllis</i>	50	70	*	Spinules on entire border	Difficult to locate or absent in VI nauplius
<i>Balanus</i> sp.	25	25	20	One spinule on either side	Absent
<i>Ch. withersi</i>	Absent	Absent	Absent	Very minute spinules, 7-8 on posterior-lateral sides bigger than the rest	Difficult to locate, or absent, V nauplius onward
<i>Ch. malayensis</i>	Absent	Absent	Absent	as above	May persist into VI nauplius
<i>I. cumingi</i>	50	35	35	Absent	Absent

* Not recorded.

along the entire border, including the area between two anterior horns. In the latter species, the spinulation extends little further over the bases of the anterior horns. In *Ch. malayensis* and *Ch. withersi*, seven or eight spinules located along the posterior-lateral border are bigger than those located on the lateral sides. All these spinules in these two species are however, difficult to locate when the larvae enter the fifth or the sixth stage. In *B.a. amphitrite* a single spinule is present on each of the lateral sides of the carapace. The carapace of *T. karandei* nauplii is spinuleless.

The caudal process in *T. karandei* is always longer than the abdominal process. A relative difference in the lengths of these two processes is not constant at any naupliar stages and this feature therefore is of no help in separating various *T. karandei* larvae. The caudal processes of the metanauplii of *T. karandei*, *B.a. cuamaryllis*, *B.a. amphitrite*, *B. variegatus*, *Ch. withersi* and *Ch. malayensis* measure 270, 200, 160, 115, 65 and 60 microns respectively. These lengths, however, vary considerably depending upon the growth conditions of the larvae. In the pedunculate species *I. cumingi*, the caudal process is totally lost at fourth naupliar stage.

An abdominal process is comprised of two pairs of abdominal spines, a median spine, a stem and its two rami. As with many other barnacles, the spines and spinulation on the abdominal process, their number, and their sequence of emergence or disappearance are of diagnostic value in *T. karandei*. A distal pair of abdominal spines appears at stage II and a proximal pair appears at stage III. These two pairs persist into the metanauplius stage. A similar situation is also noted in



FIGURES 7-8. Abdominal processes of the second and fourth naupliar stages of *Tetracitella karandei*; ass, abdominal segmental spinules; abs, abdominal spines; absn, abdominal bulb spinules; cds, caudal spine; pas, proximal abdominal spines; das, distal abdominal spines; ram, ramus.

B.a. amphitrite and *B.a. cuamaryllis*. In *B. variegatus* however, both the proximal and the distal pairs appear at second nauplius stage.

A single median abdominal spine between the members of the proximal pair of abdominal spines is absent in *T. karandei* fourth nauplius. This spine is present in *B.a. communis* (Pillai, 1958), *B. variegatus* (Karande, 1973b; in press), *B.a. cuamaryllis* and in a few other balanid species like *B. balanus* (Barnes and Costlow, 1961) and *B. hesperius* (Barnes and Barnes, 1959). An absence of a median abdominal spine is a distinctive diagnostic character that helps to separate the fourth *T. karandei* nauplius from many other similar nauplii of balanids.

The teeth on the labrum, their presence and pattern or their absence, are useful in separating various cirriped larvae encountered in Bombay waters. The second nauplius of *T. karandei* shows a pecten of very minute teeth on each of the lateral lobes of its trilobed labrum. In the subsequent stages, however, these teeth are lost. The labrum in these later nauplii therefore appears similar to those of *B.a. amphitrite* and *B. variegatus* and lacks teeth. In *B.a. cuamaryllis*, two or three sub-equal teeth are present on the middle lobe of the trilobed labrum. In *I. cumingi*, the labrum has an indented free margin that bears four to six teeth. These teeth are retained until the end of the metanauplius stage. The second nauplii of *Ch. withersi* and *Ch. malayensis* bear a series of 7-8 teeth. All other stages of these species, however, bear only two prominent teeth.

DISCUSSION

In general, the development of cirriped larvae is very uniform (Barnes and Barnes, 1959). The development of tetracelitellan barnacles, as judged by the present study on *T. karandei*, is no exception to this. The similarity between balanid and tetracelitellan metamorphosis, in fact, is so close that in the absence of detailed morphological descriptions, nauplii of these barnacles are likely to be mistaken for each other. For instance, the hitherto undescribed larvae of *T. karandei* could have been easily mistaken for the more common balanid larvae. This, however, is not true of the chthamalid and the pedunculate species encountered in Bombay waters. These barnacles follow the general cirriped metamorphosis plan but their identity as chthamalid or pedunculate larvae can be readily established on the basis of the presence or the absence of certain important morphological characters.

The present description of *T. karandei* larvae will permit their ready separation from the other cirripid larvae encountered in Bombay waters. Some of the salient features of the nauplii of this species are the larger dimensions, smooth carapace border, large posterior carapace spines, the sculpturing of the rami and a distinctive spinulation of the abdominal bulb. The nauplii of this species, because of their larger sizes cannot be mistaken for those of the chthamalid and the pedunculate species. They also cannot be confused with the larvae of *B. variegatus* or *B.a. euamaryllis* both of which have highly spinulated carapace borders. These nauplii have some resemblance with comparatively smaller sized larvae of *B.a. amphitrite*. Notwithstanding, the second and the third nauplii can be separated from the corresponding larvae of *B.a. amphitrite*, because in the latter the carapace bears a small but distinct spinule on its either side. The fourth, the fifth and the sixth nauplii of *T. karandei* can be separated from the corresponding larvae of *B.a. amphitrite*, because in the latter species the posterior carapace spines are strikingly shorter than those of the former one.

The larvae of *T. karandei*, like those of *B.a. amphitrite*, *B. variegatus*, *Ch. malayensis*, *Ch. zethersi* and *I. cumingi* examined here, take generally eleven or twelve days to reach the cypris stage. The first nauplius of *B.a. amphitrite* may at times reach the cypris stage within five days, which is the shortest recorded larval cycle for any operculate barnacle species.

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SUMMARY

Tetracelitella karandei and *Tetracelita purpurascens* are two intertidal species encountered along the Bombay coast of India. The larval stages of *T. karandei* from the first nauplius through cyprid larva are described and illustrated. The naupliar characters such as setation of antennules, carapace sculpture, and the occurrence of the abdominal bulb and caudal process have been critically examined. Their usefulness as characters of diagnostic value is discussed. The naupliar stages of this

species exhibit features, notably the spinulation of the carapace and an abdominal process, which permit their ready separation from the nauplii of all other local species. The present study strengthens the view that, in general, development amongst cirriped nauplii follows a uniform pattern.

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